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Empirical Guidelines for Use of Irregular Wave Model to Estimate Nearshore Wave Height

by

Michael G. Mattie

TECHNICAL PAPER NO. 82-1

JULY 1982

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An irregular wave technique based on a method developed by Goda (1975) and the SPM method for predicting nearshore wave height are compared with wave gage measurements from the CERC Field Research Facility. The SPM method is a classical monochromatic approach, while the irregular wave technique attempts to represent the actual distribution of ocean waves.

These two techniques have certain limitations and ranges of applicability. Comparisons with field data will better define the limits and proper use for these techniques. The performance of the models is evaluated for a variety of wave conditions and water depths.

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PREFACE

This report presents a comparison of field wave gage measurements with nearshore wave height predictions, which were generated by two techniques: an irregular wave model (Seelig and Ahrens, 1980) based on the method of Goda (1975) and the Shore Protection Manual (SPM) method (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977). The field gage measurements were gathered at the Field Research Facility (FRF) at Duck, North Carolina. The work was carried out under the U.S. Army Coastal Engineering Research Center's (CERC) Wave Estimation for Design work unit, Coastal Flooding and Storm Protection Program, Coastal Engineering Area of Civil Works Research and Development.

The report was prepared by Michael G. Mattie, Physicist, under the general supervision of Dr. C.L. Vincent, Chief, Coastal Oceanography Branch, and Mr. R.P. Savage, Chief, Research Division. The author expresses appreciation to E.F. Thompson, CERC, for the Raleigh distribution analysis and to D. Orndorff for data reduction.

Technical Director of CERC was Dr. Robert W. Whalin, P.E.. upon publication of this report.

Comments on this publication are invited.

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TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

CONTENTS

FIGURES

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

SYMBOLS AND DEFINITIONS

d	stillwater depth
d_b	depth of water at breaking wave
H_b	wave height at breaking (breaker height)
H_o	deepwater significant wave height
H_s	significant wave height or average height of the highest one-third of the waves
H_{s-obs}	significant wave height measured by FRF gages
H_{s-pred}	significant wave height predicted by irregular wave model
H_{SPM}	wave height predicted by SPM method
σ	variance of sea-surface elevation

EMPIRICAL GUIDELINES FOR USE OF IRREGULAR WAVE MODEL TO ESTIMATE NEARSHORE WAVE HEIGHT

by
Michael G. Mattie

I. INTRODUCTION

The techniques for estimating nearshore wave height rely on theories based on one of two assumptions about the nature of waves. The assumption of monochromatic waves is the basis for the technique of selecting design waves discussed in Section 7.12 of the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977). A second approach is to treat the waves as irregular, with wave height and period varying from one wave to the next. Seelig (1979) presents a technique for estimating nearshore significant wave height, originally suggested by Goda (1975), based on this irregular wave assumption. Seelig and Ahrens (1980) enhance this technique to include wave refraction.

The present report compares the predictions of the enhanced irregular wave technique with field measurements taken at CERC's Field Research Facility (FRF) at Duck, North Carolina. A range of conditions for which the technique is applicable can be defined from these comparisons. The predictions of the SPM method are also compared with the results from Seelig and Ahrens' technique and with the FRF field measurements.

II. DEFINITION OF WAVE HEIGHT

This report examines the quantity ocean wave height as measured by gages and as predicted by two techniques; however, the way each technique defines or computes ocean wave height differs. Therefore, it is necessary to examine the definitions to ensure that these differences are recognized in comparisons of similar physical properties of waves and that these comparisons are meaningful.

The wave gage records an approximately 17-minute time series of the water surface elevation. This measurement shows waves that are irregular having a distribution of wave height and period. The time series is transformed to the frequency domain where a spectrum representation of the wave data is commonly used. The significant wave height, which is defined as the average of the one-third highest waves, is then calculated as a statistical quantity from the spectrum. This calculation is possible because the integral of the spectrum over all frequencies is the variance of the measured time series. Longuet-Higgins (1952) showed that if the individual waves in a set of waves follow a Rayleigh distribution for the heights, then the significant wave height, H_s, is equal to four times the square root of the variance of the sea-surface elevation, $H_s = 4\sigma$. This assumption of a Rayleigh distribution is well established for moderate to deep water. However, it may not always be the case in very shallow water near wave breaking conditions. When this assumption does not hold, 4σ will only be a measure of the standard deviation of the sea surface, but will not necessarily equal the significant wave height. The wave heights, H_s, measured in this study were calculated from the variance as 4σ.

The irregular wave model used for prediction of nearshore wave height in this report calculates the distribution of wave heights. However, a single

wave period is assumed in the calculations. Given a deepwater significant wave height and wave period, this model then assumes a Rayleigh wave height distribution. At points in shallower water depths, this distribution is modified. At each calculation point closer to shore the waves that break are removed from the distribution. Determining whether a particular wave height breaks depends on water depth and other factors (Goda, 1975). The significant wave height at shallow-water points is then calculated from the modified distributions probability density function. At points closer to shore there is no assumption of a particular wave height distribution but rather the distribution is modified according to processes included in the model.

The SPM method makes a further simplification relative to the irregular wave model. It assumes a sinusoidal wave of a single period and wave height. As an initial input to this technique, when the deepwater spectrum is available, the period is set equal to the period for the peak of the wave spectrum and the wave height equal to the significant wave height. These are reasonable choices only if the spectrum has only one narrow peak.

III. APPROACH

Seelig (1979) generated design curves for wave height prediction using the computer program GODAS (Seelig, 1978). For this study a modified GODAS program, which includes refraction, was used to predict the wave height at the FRF pier wave gage locations. The field measurements were made with several Baylor staff gages mounted on the pier and one waverider buoy located 2.8 kilometers offshore in a water depth of approximately 16.8 meters. The significant wave height and peak period from the waverider buoy data were used as the deepwater wave inputs to this wave height prediction program. The water depths at the several Baylor gages were taken from weekly leadline soundings made along the pier, which were corrected for the tide.

An offshore bar is often present at the FRF. For the Baylor gage locations shoreward of the bar where the water depth was greater than at the bar crest, the depth at the bar crest was used as the input to the program. Seelig (1979) recommends this approach when using the technique where an offshore bar is present. The final input is the wave direction, which was measured from radar imagery taken either simultaneously with or within an hour of the gage measurements.

During the period September 1978 to March 1979, a total of 21 cases were chosen for study. As required by the irregular wave technique, single wave train situations were selected. The data set included a variety of wave periods (4 to 13 seconds) and significant wave heights (0.9 to 2.7 meters).

IV. COMPARISON OF PREDICTIONS WITH MEASUREMENTS

Preliminary comparisons of the irregular wave model predictions with the measured significant wave height showed that an analysis of the results should be segmented into three types of wave conditions: swell waves (waves propagating into FRF area which were generated offshore and are no longer receiving energy input from local wind), sea waves (waves still being generated by local wind), and deepwater significant wave height, H_o, greater than 1.8 meters. Figure 1 shows examples of each condition. The September wave spectrum shows a prominent swell wave train. The plot of wave height versus location for the

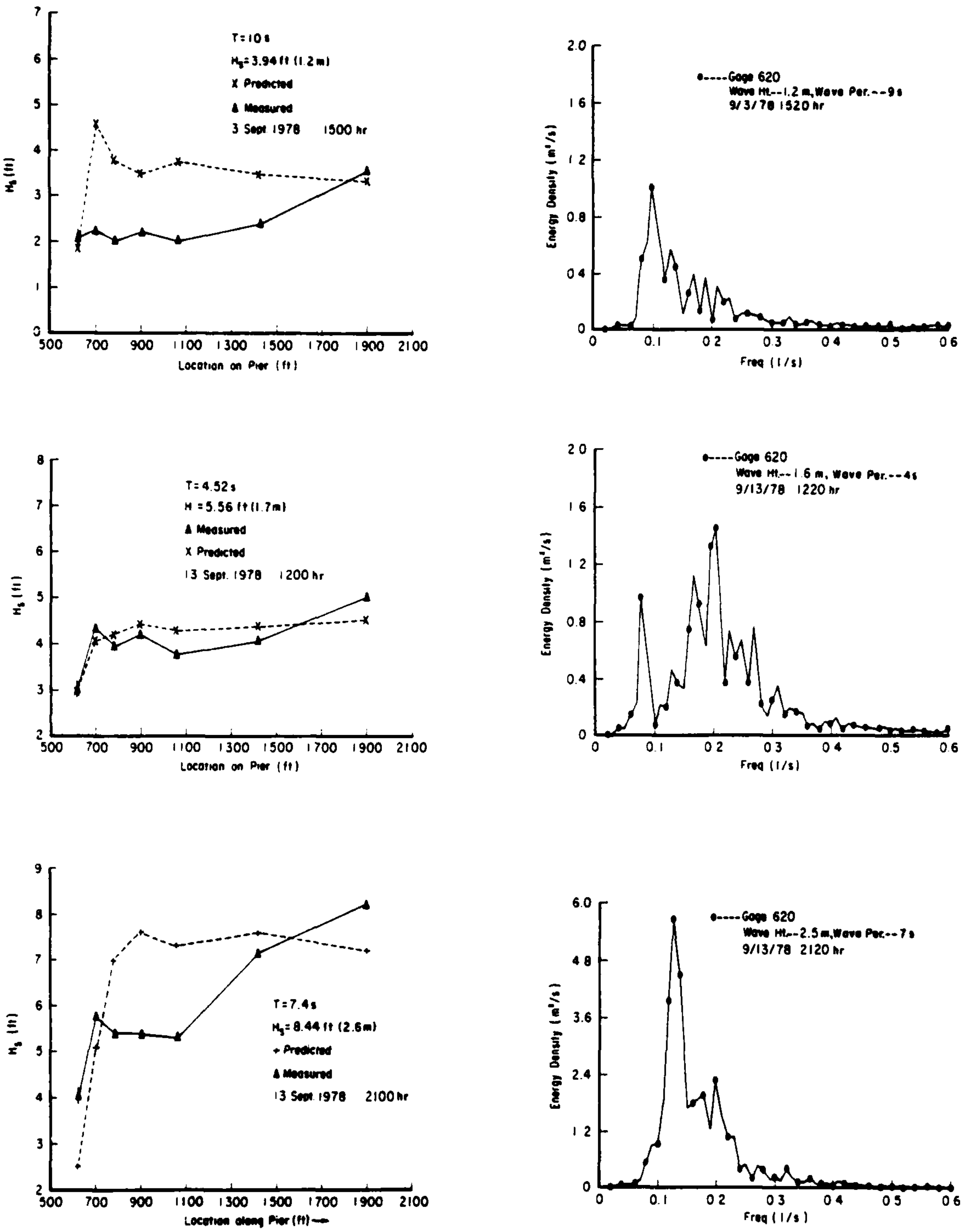

Figure 1. Wave gage H_s and spectra plots for three wave conditions: swell (3 September, 1500), sea (13 September, 1200) and H_o > 1.8 meters (13 September, 2100).

predicted and measured results shows an overestimation of the significant wave height, H_s, by this prediction technique. For 13 September at 1200 a developing sea is dominant and the comparison shows good agreement. However, at 2100 the same day the seas had grown to more than 2.4 meters and the irregular wave technique overpredicts H_s for the deeper water and underpredicts for the relatively shallower water depths. A more quantitative description of these trends can be obtained through analysis of all the data for each of these cases.

The entire data set for the irregular wave technique is shown in Figure 2. The ordinate is the ratio of the predicted significant wave height, H_{s-pred}, to measured significant wave height, H_{s-obs}. This ratio would be equal to one for perfect agreement between the model and measured results. The ratio of the water depth to measured H_{s-obs} is plotted along the abscissa. The SPM method (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977) predicts that the ratio of breaker depth to breaker wave height is between 1.5 and 1.2 for the conditions encountered for these field measurements. The scatter in the data shown in Figure 2 is of the same magnitude as seen by Goda (1975), Fig. 12) in data from Sakota Port. Subsets of the data are plotted in Figures 3, 4, and 5, which show the results for the three wave categories: sea, swell, and $H_o > 1.8$ meters. An analysis of these plots leads to the following conclusions on the performance of the irregular wave prediction technique for estimating H_s:

(a) At or below the breaker limit (i.e., $d/H_s < 1.5$) the model underpredicts H_s by as much as 40 percent.

(b) For sea conditions (i.e., waves are still in the stage of generation by local wind) and $H_o < 1.8$ meters, there is good agreement between predicted and measured results. The predicted H_s is on the average 13 percent greater than the measured H_s. The ratio H_{s-pred}/H_{s-obs} has mean 1.13 with a standard deviation of 0.14. For all available cases of this type $d/H_{s-obs} > 2$.

(c) For swell waves where $d/H_{s-obs} > 2$ there is significant overprediction by the model. The predicted H_s exceeds the measured H_s by as much as 150 percent with the average on the order of 50 percent. The best agreement was for the measurements made at the Baylor farthest offshore in about 7.6 meters of water. The ratio H_{s-pred}/H_{s-obs} has mean of 1.5 with a standard deviation of 0.38.

(d) For $H_o > 1.8$ meters, the model performance is mixed. For observations at the Baylor gage in the deepest water ($\sim$ 7.6 meters) the model shows good agreement with the gage measurements. For the other locations, there is a tread where the model performance decreases as d/H_{s-obs} increases. At $d/H_{s-obs} \simeq 1.5$ the agreement is good. As d/H_{s-obs} increases the overprediction of H_s by the model increases rapidly until at $d/H_{s-obs} = 4.0$ the model is overpredicting by about 80 percent.

To determine how the SPM method compares to the field data, the SPM method, given the deepwater wave height H_o and wave direction, can be used to predict the wave height at points close to shore (decreased water depth). This method applies the linear wave theory for refraction and shoaling to obtain wave

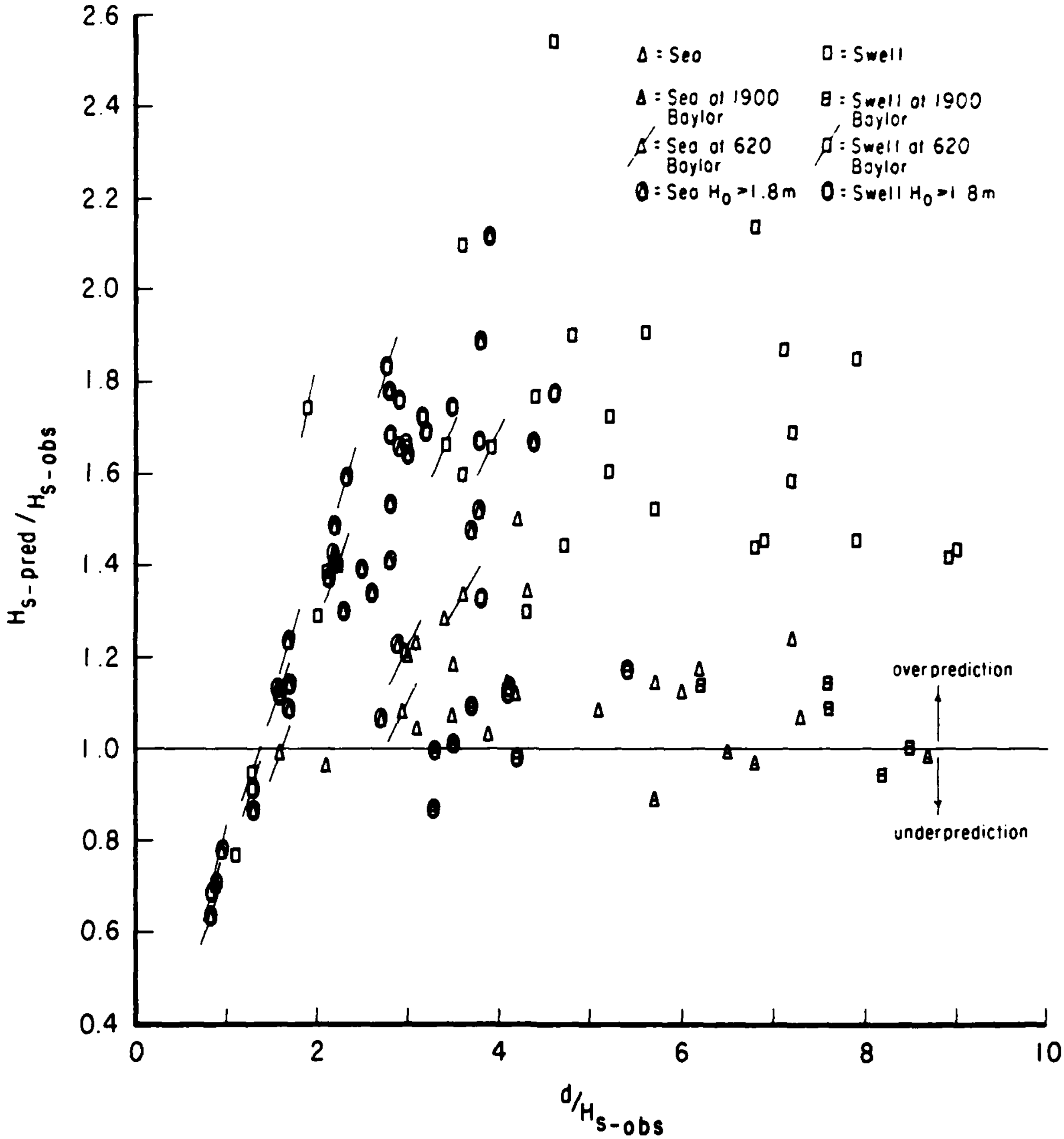

Figure 2. Plot comparing irregular wave technique predicted wave height, $H_{s\text{-pred}}$, with measured $H_{s\text{-obs}}$ for entire data set.

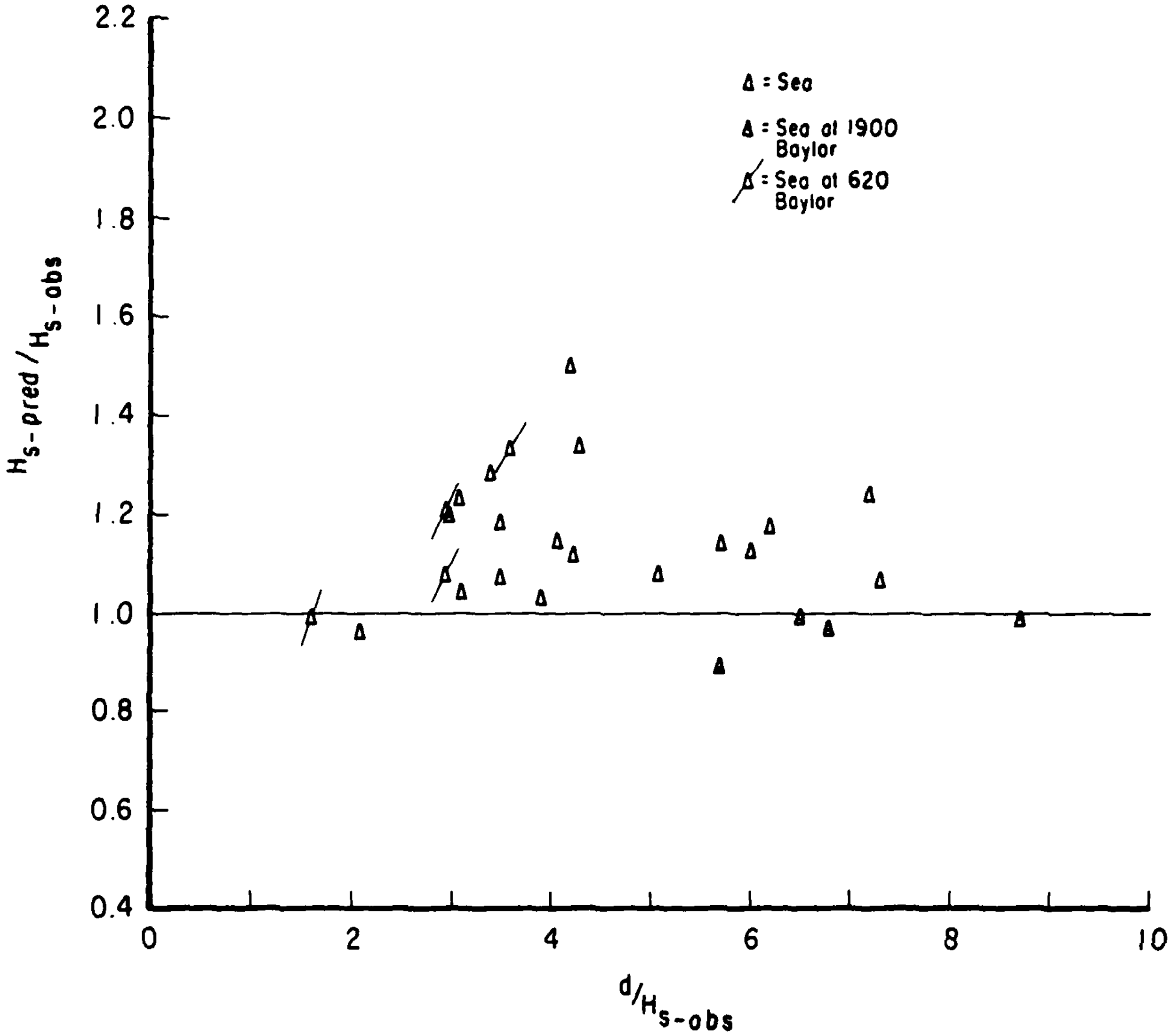

Figure 3. Plot comparing $H_{s\text{-}pred}$ with $H_{s\text{-}obs}$ for sea wave cases.

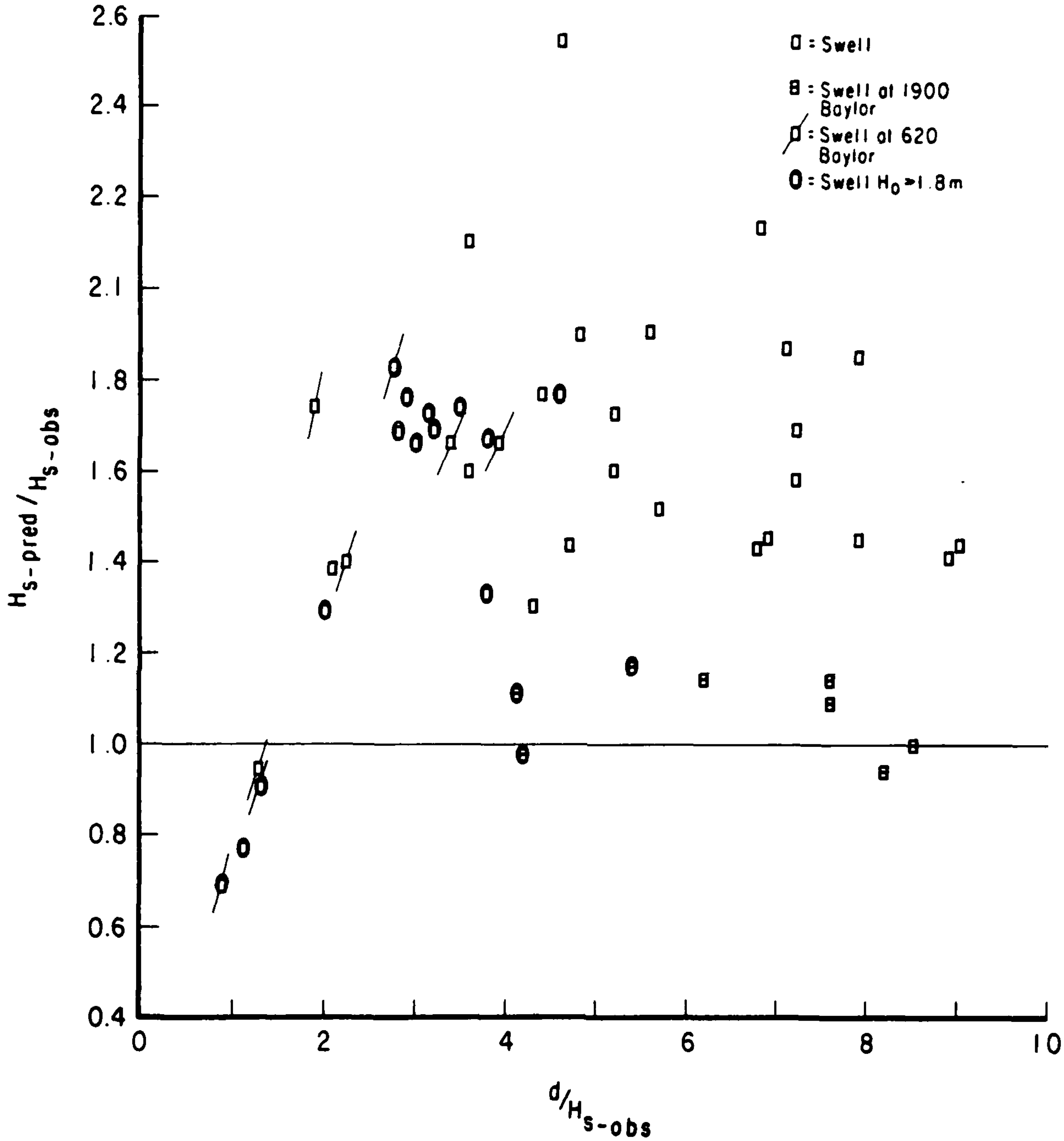

Figure 4. Plot comparing H_{s-pred} with H_{s-obs} for swell wave cases.

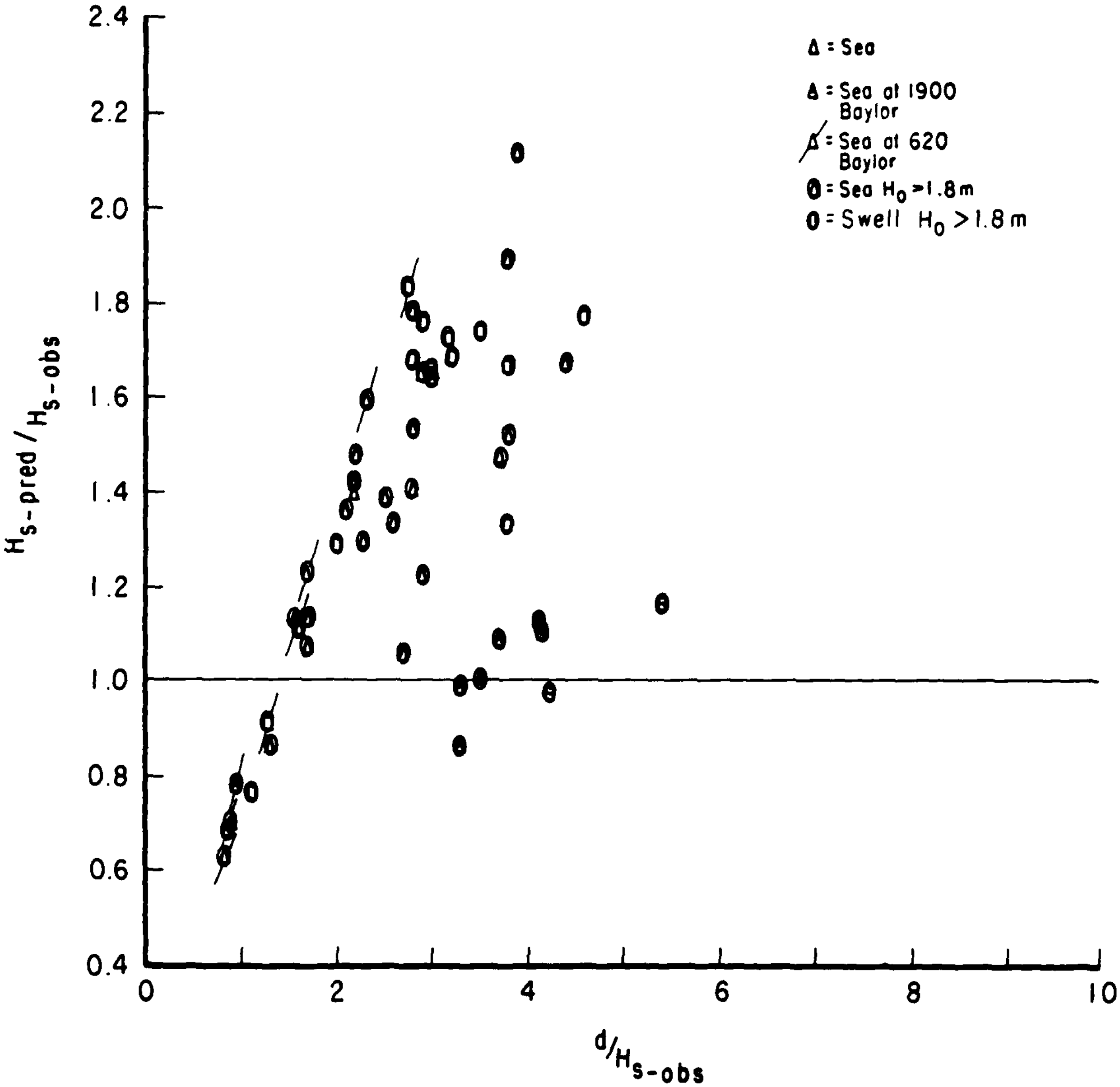

Figure 5. Plot comparing $H_{s\text{-pred}}$ with $H_{s\text{-obs}}$ for H_o > 1.8-meter cases.

height predictions. It is not a spectrum method. Rather, this model assumes a single frequency sinusoidal wave where the usual procedure, when measured deepwater wave spectra are available, is to set the amplitude equal to $H_o/2$ and the period equal to the significant wave period. In this study, instead of applying the SPM equations to predict the wave height, the easier to use technique presented by McClenan (1975) was employed. The McClenan technique utilizes a monogram which was constructed from the SPM equations and gives the same results. The inputs to the monogram technique are the period, the deepwater wave height, the deepwater wave angle, and the depths of interest. Figure 6 shows the comparison of the wave heights predicted by this technique with the measured H_s. There are no comparisons in the figure for $d/H_{s-obs} < 2$ because the SPM method is applicable only for water depths greater than the breaker limit ($d_b/H_b \sim 1.3$).

An examination of Figure 6 shows that the same segregation of the data into swell, sea, and $H_{1/3} > 1.8$ meters, as in the previous comparison for the irregular wave technique, is appropriate for linear wave technique predictions. In general, the following similar trends in the predictions are seen:

(a) For swell waves there is significant overprediction. The mean value of H_{SPM}/H_{s-obs} is 1.59 with a standard deviation of 0.35.

(b) There is good agreement for the Baylor gage located in the 7.6-meter water depth. The mean is 1.04 with a standard deviation of 0.08.

(c) For sea with $H_s < 1.8$ meters, the agreement between the model and measurements is better than for swell but still overpredicting. The mean is 1.25 with a standard deviation of 0.17.

(d) For $H_o > 1.8$ meters, again the results are mixed. The prediction agrees with the measurement for the Baylor gage in the 7.6-meter depth. The model overpredicts for the other gages. The mean of H_{SPM}/H_{s-obs} is 1.51 with a standard deviation of 0.34.

In general, in evaluating each of the two models from the comparison with the gage measurements, it can be seen that the predictions of the irregular wave-based model were about 10 percent better than those for the McClenan-SPM model based on monochromatic waves. In addition the irregular wave model can be used in much shallower water, while the monochromatic wave model is not applicable in water shallower than the breaker depth.

V. EVALUATION

As indicated in the previous section, there are wide variations between the model estimates and the field measurements of wave height. Two factors that contribute to these variations are the bathymetry and the way the wave heights are calculated.

Bathymetric surveys at the FRF show that there is a depression near the end of the pier. This causes some wave energy to be refracted away from the gages, resulting in lower wave height measurements. The prediction techniques

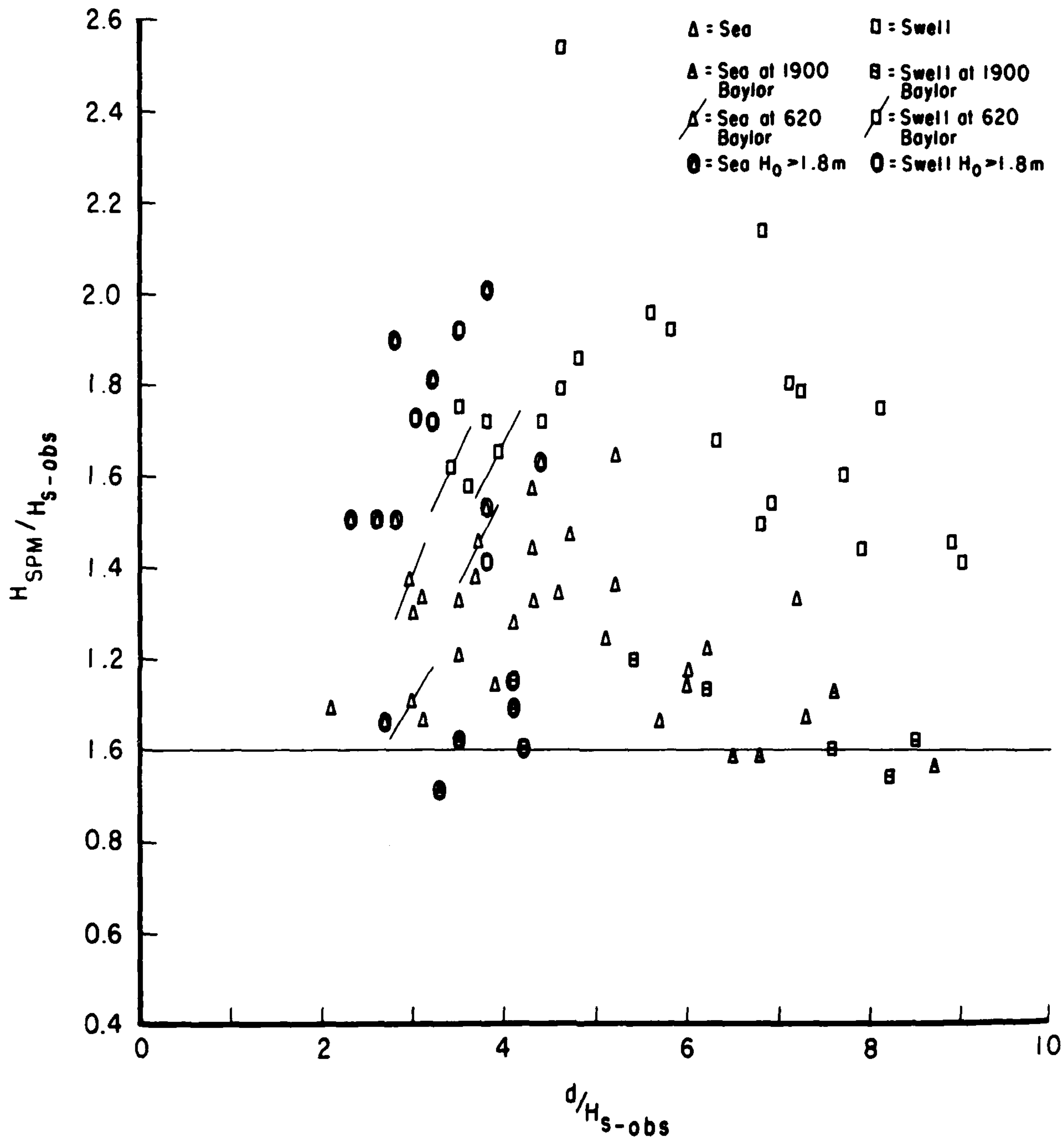

Figure 6. Plot comparing predicted wave height by SPM technique, H_{SPM}, with measured wave height, H_{s-obs}.

assume that the bottom contours are straight and decreasing. To estimate the magnitude of the effect of refraction due to this depression, a spectral refraction model was run for both the existing bathymetry at the FRF and a smoothed bathymetry (depression removed) for deepwater wave conditions selected from the set of data analyzed for this study. The results show that for the Baylor gages, where the models overpredict, the correction tr measured wave height for this refraction would be less than 10 percent. This is much less than the overprediction of the models, which is about 50 percent. For the Baylor gages in the shallowest water depth, where the irregular wave model tends to underpredict, the refraction correction increases the measured wave height from 10 to 50 percent, which makes the disagreement between the irregular wave model and the measurement even greater.

The second factor, which may contribute to the differences between prediction and observation, is the assumption of a Rayleigh distribution in the calculation of significant wave height for the measured data. If the wave heights do not have a Rayleigh distribution then the measured 4σ will not be equal to the average of the one-third highest waves. To get an estimate of how large an error results from using the 4σ statistic for the measured H_s, the individual wave heights were counted for selected time series from the data set. From this count, the average of the one-third higher waves was obtained. The distributions, which were obtained, showed that the wave heights for the most part were very nearly Rayleigh distributed. The 4σ values for H_s differed from that obtained by counting waves by less than 10 percent; for a majority of cases the differences were less than 5 percent. Correction of the measured wave heights for errors due to using 4σ for significant wave height does not significantly affect the results of the comparisons between wave measurements and the model predictions. For most cases this correction tends to increase the discrepancy between measurement and irregular wave model prediction.

The comparisons showed that the irregular wave model is better than the SPM-McClenan technique for predicting nearshore wave conditions. The irregular wave model is more representative of the physics of the wave processes, and it can be used shoreward of the SPM-defined wave breaking point, which assumes a single sinusoidal wave. It also gives results which, on the whole, are in better agreement with measurements than the SPM-McClenan technique. However, the comparisons of the irregular wave model results with the gage measurements show large differences. In general, as the waves enter shallow water the model overpredicts. This indicates that there are significant dissipative effects that are not being accounted for by the model. In very shallow water, the model often underpredicts in the region in or near the surf zone. A hypothesis for this underprediction is that the extra measured wave energy is due to waves that have broken and re-formed, a process that is not included in the irregular wave model.

VI. SUMMARY

Comparisons of nearshore significant wave heights as estimated by an irregular wave procedure and by the SPM-McClenan technique with gage measurements show that the irregular wave model is an improvement over the SPM-McClenan technique. Yet for many cases there remain large differences between the model predictions and gage measurements. Therefore, care should be taken when using the model, especially in very shallow water where the model often underpredicts for cases of high deepwater waves.

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